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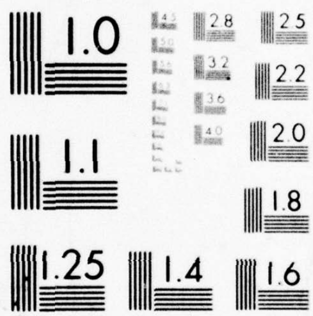

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VELOCITY MEASUREMENTS ON THE AERODYNAMIC WAKE OF A HOVERCRAFT USING LASER DOPPLER ANEMOMETRY

by

W. E. R. Davies and J. H. deLeeuw

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Dr. P. Sullivan kindly made the ACV facility available for this study and provided some of the impetus which prompted this investigation.

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Summary

The laser Doppler technique has been applied to determine the aerodynamic wake velocity components behind a tethered air cushion vehicle (ACV) which runs close to a confining wall. Two velocity components were measured for a number of locations behind the vehicle, using the fringe mode and forward scattering from unseeded air. Some auxiliary forward and back scatter experiments with pulsed and D.C. lasers are also described.

A video tape recorder was used to record all the laser Doppler data, which could then be processed by an oscilloscope, a spectrum analyser or a DISA 55L signal processor.

Results are presented which show that the stabilized wake effects are minimal for the UTIAS ACV and its associated facility.

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1. INTRODUCTION

Studies of air cushion vehicle (ACV) operating parameters have been carried out by a number of agencies; these have involved commercial and research vehicles as well as scale models. UTIAS has in the past used a small tethered model on an indoor track for some ACV investigations. Modelling has obvious advantages from the viewpoint of development costs, but unfortunately because of problems associated with some ACV features, particularly the skirt material, realistic small scale modelling is difficult to attain. Recently, a large scale ACV testing facility has been completed at UTIAS which includes a circular enclosed track and peripheral equipment permitting extensive diagnostics to be carried out during the operation of tethered ACV's.

One of the questions arising in the use of a tethered vehicle when operated in close proximity to a confining circumferential wall, is that the craft may run in its own aerodynamic wake. The circulation, or stirring effect, caused by the repeated passage of a vehicle over the same location has been investigated by tuft testing and such studies have shown that the wake spills radially; however, such tests provide little information on the magnitude and duration of the velocity components.

The problem of quantifying the residual wake velocity is somewhat intractable using conventional anemometers, if complete spatial and temporal mappings are required over a plane perpendicular to the vehicle's motion. The rapid movement of a material probe to a selected station behind the vehicle involves mechanical complications, and would introduce undesirable signal transients.

The laser Doppler velocimeter (LDV) approach is well suited to this type of problem, the laser "probe" may remain "in situ" during passage of the vehicle and the observation region re-establishes itself immediately after the vehicle has passed. The LDV does not perturb the medium during measurements, is insensitive to ambient temperature changes and can in principle provide three simultaneous orthogonal velocity component measurements.

2. THE UTIAS ACV TEST FACILITY

The ACV test facility is shown in Fig. 1 and a complete description is available elsewhere (Ref. 1). A portion of the levelled and rigid 46.7m diameter plywood track is shown in cross section in Fig. 2, and in plan view in Fig. 3. The ACV is tethered to a central post which carries slip rings for transmission of control and housekeeping signals from the craft to an observation and control room. A television camera mounted on this post views the vehicle at all times, providing for real time monitoring from the control room and allowing video records to be made of selected runs.

A tubular framed geodistic structure supports the galvanised sheet steel dome covering the track and crushed gravel interior floor. The circumferential continuity of the dome wall at track level is broken by a series of louvered doors which together with a centrally mounted roof fan provide for evacuation of engine exhaust fumes. A much larger perturbation in the wall surface is presented by the service area and control room bay shown in Fig. 1b.

The location chosen for performing the LDV measurements shown in Fig. 3 was selected to allow for a maximum smooth wall length prior to the laser observation region, to permit the interference-free formation of a persistent circulation. In keeping with the precepts of allowing the stirring effect to develop freely, the aerodynamic profile of the LDV apparatus was also kept as low as possible. A hydraulically controlled ramp is available which allows controlled perturbations to be introduced in the track surface, however, this feature was not used during any of the tests conducted for this report.

3. THE LASER DOPPLER SYSTEM FOR THE ACV WAKE MEASUREMENTS

The laser Doppler method has been comprehensively covered in the open literature (Refs. 2, 3 and 4); for convenience a brief description of the technique is given in Appendix 1.

The fringe, or dual beam mode mode, was chosen because it has the advantage over the reference beam mode in providing higher signal to noise ratios (S/N), when few scattering particles are available (as determined in the course of some auxiliary experiments not described in this report).

The LDV system described in this section was selected from several configurations that were evaluated prior to conducting the ACV measurements. A brief description of the performance of some of the other arrangements tested is given in Appendix 2.

The Mie forward scatter signal from the 'natural contaminants' in air is several orders of magnitude larger than the corresponding back scatter signal. This is a powerful incentive for working in the forward direction in applications where this approach is acceptable and the available laser power is inadequate for back scattering.

A forward scatter viewing angle was chosen since it was a prime requirement of this experiment that the LDV diagnostic equipment operate without artificial seeding. The use of natural scatterers enabled the ACV to operate without filtration of the engine air intake, and provided a realistic appraisal of the capabilities of an LDV system under severe wind, vibration and particle-rare conditions.

The apparatus employed for the ACV wake measurements is shown schematically in Fig. 4. A 50 mW He-Cd laser beam, Fig. 4a, is first expanded by passing it through the achromatic lenses L_1 and L_2 (focal lengths 25.4 mm and 98 mm respectively). The lens L_2 can be adjusted along the laser beam axis to provide a focus at any chosen location across the track. Prisms P_1 and P_2 enable the beam to be incident on the beam splitter cube at 45°, the latter divides the incident beam equally and directs the resultant beams to the mirrors M_1 and M_2. Appropriate adjustment of M_1 and M_2 enables the intersection of the beams to be positioned at any location.

The fringe pattern at the focussed common region of the intersection of the two beams may be chosen to be horizontal or vertical by rotation of the optics support about the pillow blocks R_1 and R_2 thus permitting velocity measurements to be made along and perpendicular to the track. The mirror M_4, Fig. 4b, placed at track level allows for lateral and elevation adjustments of the probe region, and produces no interference to the ACV tether line.

The optical arrangement just described enables the path equality criterion of Foreman (Ref. 5) to be fulfilled and allows for considerable flexibility in locating and focussing of the observation region. A translucent screen temporarily placed at the selected observation station allows the beam foci and overlap to be adjusted; the illuminated spot on this screen can then be focussed via the Fresnel lens onto the photomultiplier iris aperture, thus completing the optical alignment for a particular observation station. The variable iris diaphragm was adjusted to allow only the image of the scattering volume to pass to the photomultiplier; this procedure still permitted the whole of the probe region to be observed at all times.

Optimum signal to noise conditions were obtained when the Fresnel lens viewed the probe region at a slight angle, i.e., when the angle between the laser-beam's bisector and the optic axis of the Fresnel lens was ~ 0.09 rads. This off-axis viewing is necessary to reject the halo associated with each laser beam and which, if included with the scattering signal, degrades the S/N. It was found in laboratory tests that a stop placed at the observation region, and of sufficient size to reject only the halo, enabled the Fresnel lens to view the scatter volume at angles down to ~ 0.02 rads, improving the S/N by a factor of ~ 5. Spatial filtering can reduce the beam halo significantly; it should be carried out after the mirror M_4 to be most effective. However, cleaning up the beam in this manner is inconvenient and it is easier to circumvent the halo problems by using more laser power and viewing the scattering region at a somewhat larger angle, the route followed in the present experiment. Some operating parameters for the optical system employed in the actual ACV measurements are listed in Table 1.

TABLE 1

OPERATING PARAMETERS FOR THE LDV SYSTEM

The following conditions relate to the maximum and minimum distance from the scattering volume to the Fresnel collector lens.

	MINIMUM	MAXIMUM
Location of the observation region (height above track, distance to track centre line)	(0.52m, -1.22m)	(0.36m, +1.80m)
Fringe spacing (δy)	3.03×10^{-3} cm	4.31×10^{-3} cm
Length of probe volume (ΔZ) to the $1/e^2$ intensity level points	9.3 cm	18.8 cm
Diameter of probe volume ($2w_o$)	6.8×10^{-2} cm	9.6×10^{-2} cm
Beam intersection angle (θ)	0.84 deg.	0.59 deg.
Doppler frequency (f_D)	33.0 kHz/ms^{-1}	23.2 kHz/ms^{-1}

Wind shields were required to protect the optical system from the wind gusts generated by the ACV thrust and lift fans during the vehicle passage. These shields were mechanically isolated from all the optical components, the latter being supported on tables resting on concrete pads. A stable fringe pattern could be produced across the track diameter (45m) during a test run with the hovercraft, confirming the protection provided by the wind shields.

4. EXPERIMENTAL PROCEDURES FOR DATA COLLECTION

For personnel safety considerations the apparatus located at the track must operate unattended whilst the hovercraft is in motion. Accordingly, the signal from the photomultiplier is brought to the control room through 65m of 50Ω coaxial cable after being preamplified for this purpose by the circuit shown in Fig. 5.

The dimensions of the vehicle employed for these tests are shown in Fig. 6. Hovering power is applied only after the vehicle has attained a prescribed forward velocity ensuring that the centrifugal force is sufficient to overcome the inward force due to the tether line weight.

During the initial tests the ACV performed as many as 30 circuits in attempts to develop an air circulation pattern around the track. When it became evident that the first circuit results were not significantly different from those made after many runs, the test procedure was modified and limited to 4 or 5 laps for each observational point selected.

Two different designs of multicell flexible skirts were used during the test runs, but no difference could be detected in the laser Doppler results at the changeover.

5. DATA RECORDING AND SIGNAL PROCESSING PROCEDURES

A DISA 55L Doppler signal processor was available for the experiment and was used for reducing most of the recorded data presented in this report. In working with the DISA unit it appeared that unless a reasonable facsimile of the expected Doppler signals could be presented to the instrument to permit prior adjustment of threshold, gain and filter settings, then the capabilities of the instrument for the particle-rare, real-time conditions of this experiment were somewhat restricted.

Because of the difficulties experienced in attempting real-time processing it was decided to produce a permanent record of the Doppler signals obtained from all the ACV tests. This procedure provided considerable flexibility in the data reduction and vehicle operating procedures and made possible inter-comparison of the Doppler frequency determination by different techniques. The recording approach has the obvious additional advantage of requiring no complicated prior adjustments, and the production of a permanent real-time record of events that may be difficult or expensive to duplicate.

The photomultiplier Doppler signals for each ACV run were recorded on the video channel of a Sony AV 3650 audi-video tape recorder, with simultaneous voice annotation onto the audio track. A 10 kHz sine wave was dubbed onto the audio channel at selected intervals of the record during data reduction. This

signal served as a timing reference, and on playback was coupled to a counter providing an accurate clock during detailed examination of the records at slow speeds.

The tape recorder incorporates a slow speed playback capability with a reduction of ~ 34:1, and a pause control which permits the tape to be stopped at any desired record time, enabling individual Doppler signals to be examined at length. The tape can also be moved slowly by hand permitting examination of each individual Doppler signal on the recording; a very convenient feature if velocity transients are suspected. During this type of detailed examination the record time is accurately known via the counter display (if the latter is set to accumulate the 10 kHz audio timing signal).

6. REDUCTION OF THE LASER DOPPLER SIGNALS

The tape recorded laser Doppler signals from the photomultiplier could be reduced by the following procedures:

(1) Direct determination of the Doppler frequency from storage oscilloscope displays.

(2) Frequency determination from spectrum analyser displays.

(3) Use of a DISA 55L Doppler signal processor.

Some caution must be exercised when employing methods (2) and (3) with signals derived from the tape recorder when the latter is operating in the slow-playback, or pause mode. When the playback is slower than the original recording rate the tape recorder's rotating pickup heads sample the same tape frame many times (one frame occupies ~ 17 msec and is sampled 60 times/sec).

A spectrum analyser display of this recurring waveform will show spectral lines of the frame repetition frequency which may be confused with the Doppler modulation frequency components. These spurious spectral components are easily recognizable since they move on the spectrum analyser display when the tape is moving, whereas the transformed Doppler frequency components are stationary over one or more frame intervals. An additional validity check can be made by altering the spectral dispersion, in this case the location of those signals of Doppler origin will change but those associated with the framing period will not.

A short burst of high frequency noise of about ~ 1.5v peak and 1 ms duration occurs at the beginning of each frame on playback; this is of little consequence when using the first two methods of frequency analysis, since it only results in the loss of a small portion of the record. The DISA signal processor was unable to track the recorded Doppler signals in the presence of these noise bursts with the tape recorder in the slow playback or pause mode, although it readily tracked continuous sine wave recordings of varying frequency. To confirm whether the DISA unit would accurately track the recorded Doppler signals at all playback speeds, the circuit shown in Fig. 7 was used to clamp the output signal for a short time during each video frame, corresponding to the noise interval. With this noise suppression circuit in place the DISA unit gave an accurate representation of the Doppler frequency for the complete range of Doppler waveforms encountered in this experiment. The DISA unit occasionally

gave a spurious output even when repeatedly sampling the same Doppler burst, a phenomenon also observed when the tracker was used to examine real-time Doppler scatter signals derived from a spinning plexiglass disc during some preliminary tests.

7. EXPERIMENTAL RESULTS

The vector velocity obtained at various locations of the laser probe region, in a fixed plane perpendicular to the track, are shown in Figs. 8 and 9. Each record shown has been derived from the 3rd or 4th circuit of the vehicle after a stationary start from the control room, and represents a little more than one circuit of the track for the ACV. The sudden velocity increase corresponds to the instant when the rearmost occluding portion of the vehicle clears the laser beams.

Some comparison between the data reduced using the DISA tracker and that obtained from the spectrum analyser are shown in Figs. 10 and 11. The spectrum analyser data was obtained by the examination and manual recording of information from selected individual tape recorder frames. Only a small sample of the total number of usable Doppler bursts were reduced by this method due to the labour involved. The rate at which suitable scattering particles (those producing an $S/N \geq 10$), pass through the observation region varied from $\sim 5000\ s^{-1}$ immediately after the ACV crossed the observation region, to $\sim 100\ s^{-1}$ just before the vehicle reappeared at the same track location.

Originally it was anticipated that the scatter S/N would be much larger in the ACV facility than in the laboratory since the former more closely approximates an out-of-doors environment. Subsequent tests, however, showed that such was not the case — the passage of the vehicle tended to deplete the observation region of naturally occurring scattering particles during the vehicle's transit, and on occasion the scatter occurrence rate was actually lower than for laboratory air under the same optical conditions.

A hot film probe placed close to the laser beam probe region, at the outside edge of the track, was used to obtain the lower traces shown in Figs. 10 and 11; these records and those from the DISA unit were made using a chart recorder with a frequency response of ~ 100 Hz.

8. DISCUSSION OF THE RESULTS

With the observation region close to the track, the arrival of the ACV (when moving at a speed of ~ 10 m/s), can be sensed some 70 cm before it actually appears at the laser probe region. This phenomenon is most evident in runs 0 and 1, Fig. 8, where it is manifested as a rise in the measured velocity followed by a short gap in the record, the latter corresponding to the interval the beams are blocked by the vehicle. The air movement producing this sudden velocity increase may result from the layer of air which is pushed ahead of the ACV by its blunt forward structure, or the forward air spillage from beneath the flexible skirt.

The brief gap in the data of Figs. 8 and 9 during the passage of the vehicle through the observation region is followed by a sharp velocity increase and a period of high turbulence. This velocity increase is characteristic of

all the records but is less pronounced at those locations clear of the vehicle's path and removed from the dome's outer wall (e.g., runs 7 to 14 and 27 to 30 of Figs. 8 and 9).

A detailed examination of the video tape recordings shows there are large fluctuations in the Doppler frequency immediately after the ACV clears the laser beams. These frequency fluctuations sometimes show variations of 5:1 in 1 ms probably indicating considerable turbulence at those probe locations. The rapid nature of these velocity variations does not appear in the results presented here where the upper frequency limit is restricted by the strip chart recorder. For most observation locations, this turbulent period decays in just a few seconds to a quiescent state where there is little variation between successive Doppler signals.

In Appendix 1 attention is drawn to the fact that only one vector component of the scatter particle velocity is measured using the instrumentation designed for this experiment, and in addition the 180° directional ambiguity also mentioned exists for all the results presented here. An example of the directional uncertainty is demonstrated by a comparison of runs 21 and 1. Since run 21 is a sample of the propeller wake velocity components, these are most probably in a sense opposite to that of the vehicle motion. In run 1 the velocity increase, which occurs just prior to blockage of the laser beams, is associated with air moving in the vehicle direction as discussed earlier.

The maximum velocities measured are those monitored in the vicinity of the thrust propeller (e.g., runs 15 to 21); the peak value is not the same in all cases and this may be attributed in part to the variation in the vehicle speed from run to run. The air velocity for runs 15 to 21 falls off quite rapidly. This is not surprising as there is considerable mixing at this station due to the different pointing attitudes of the propeller axis as the craft moves around the circular track.

9. CONCLUSIONS

Only a few of the observational runs show indications of a persistent circulation effect, which is most evident at those locations close to track height and near the outer dome wall. Wake persistence is most obvious for those velocity components measured along the vehicle trajectory and is prominent in runs 0, 2, 3 and 33 in Fig. 8. For comparison purposes, it is pointed out that natural wind speeds in an out-of-doors environment are commonly much greater than those observed for the persistent circulation situations reported here.

From the experimental results we may conclude that wake persistence in the ACV facility is confined to regions close to the outer wall, and represents only a small fraction of the vehicle speed over most of the vehicle's cross section.

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APPENDIX 1: DESCRIPTION OF THE DUAL-BEAM OR FRINGE MODE, LASER DOPPLER SYSTEM

The system described here, and used for this report has also been called the differential Doppler system, and differs from the reference beam method in providing a real fringe pattern in the probe or observation region. In Fig. 12a, two equal intensity beams derived from the same laser are made to intersect forming an approximately ellipsoidal volume which will contain interference fringes perpendicular to the plane of the figure and throughout the common region of the two beams. A particle (usually smaller than the fring spacing δy) will scatter light as it traverses the fringe volume. For an isotropic scatterer, the scattered radiation may be observed from any direction and, for a particle moving perpendicular to the fringes and through the centre of the probe volume, will have the appearance of the waveform shown in Fig. 12c. The intensity profile of the overlapping beams determines the outer envelope in Fig. 12c and the depth of the modulation is a function of the fringe visibility. If the fringe spacing is known, then the vector velocity component normal to the fringe pattern can be determined from the modulation frequency in Fig. 12c.

It should be noted that a directional ambiguity exists with the laser Doppler systems described in this report, since the Doppler scatterer signal contains insufficient information to determine the propagation direction of the scattering particle. This uncertainty can be removed by several techniques (Ref. 6) which give the sense of the velocity and retain all the features just described.

Some useful parameters relating to the LDV method are listed below using the notation of Fig. 12:

$$\text{Fringe spacing } \delta y = \frac{\lambda}{2 \sin \theta/2}$$

$$\text{Doppler frequency } f_D = \frac{2v \sin \theta/2}{\lambda}$$

$$1/e^2 \text{ beam radius at the focus } \omega_o = \frac{f\lambda}{\pi b}$$

Focal volume dimensions to the $1/e^2$ intensity level:

$$\Delta x = 2\omega_o \qquad \Delta y = \frac{2\omega_o}{\cos \theta/2} \qquad \Delta z = \frac{2\omega_o}{\sin \theta/2}$$

Number of fringes at the maximum value of Δy:

$$N = \frac{2D}{\pi b}$$

Fringe visibility:

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

APPENDIX 2: SOME ADDITIONAL LDV OPTICAL CONFIGURATIONS

It has been mentioned in Sec. 3 that one objective of the present study was for any LDV apparatus designed for this investigation to operate without artificial seeding. In fulfilling this requirement, a number of auxiliary tests were conducted using a variety of optical configurations and employing lasers which were available in our laboratory at that time. A few of these tests are described below giving an indication of the viability of the various approaches when operating with only natural scatterers. In addition to this requirement, there were some further restraints which have been itemized below.

(i) The tether and umbilical line presented a serious impediment to the placement of the LDV apparatus, restricting most of the diagnostic equipment to the outer periphery of the track.

(ii) The spatial resolution requirements of the probe were not severe, it being merely necessary to provide adequate mapping in relation to the vehicle size; an arbitrary upper limit of 20 cm was placed on the length of the LDV probe volume.

(iii) Lack of coolant water at the test site and high humidity conditions ruled out the use of a high powered DC argon ion laser.

(iv) A scatter signal repetition rate of 100 Hz was considered desirable in view of the unknown nature of the signal.

Back-Scattering Using a 50 mW He Cd Laser

The back-scatter configuration, an obvious choice for this application, has the advantage that all the LDV equipment may be placed at one location, thereby circumventing the tether line problem. An additional feature of this arrangement is that the transmitter and detector are usually coaxial and this simplifies much of the optical alignment. Unfortunately, those particles in air which provide the largest scatter signals also direct most of the scattered laser energy into the forward direction. Our experience has shown that for clean air conditions, back-scattering is possible using 20 mW of laser power in both beams and an F/1 detector lens.

Tests using the back-scatter mode with natural scatterers in laboratory air indicated that a 50 mW He Cd laser would have provided sufficient capability for operation with the parameters shown in Fig. 13. For complete velocity mapping at all points above and across the track, the conditions of Fig. 13 could only have been met if the LDV apparatus were mounted beneath the track, not a good location when the size of the optical components was taken into consideration.

Forward and Back-Scatter Using a Pulsed Argon Laser

For the optical configurations described in this report, the most useful Doppler signals appear to originate from single large, or perhaps favourably oriented particles which produce Doppler bursts having the required S/N for processing. The frequency with which these particular particles occur sets a

limit to the time resolution of the LDV. Since an increase in laser power produces an increase in the scatter signal, it is of interest to know whether a higher power pulsed laser can raise the signal level of some of the more plentiful smaller particles to the detection threshold.

Tests were conducted with a pulsed argon laser in both forward and back-scatter configurations using the natural scatterers present in laboratory air. The nominal pulsed power output over all lines of the laser was 1 watt, with ~ 200 mW available for the 5145Å line employed in the tests. The pulse shape and width varied slightly with the pulse repetition frequency (prf); most checks were carried out at a prf = 100 Hz where the corresponding pulse width was ~ 50 μs.

In the present experiment, the dynamic range of velocities is about 20:1, imposing a condition that the Doppler frequency should range from ~ 0.2 to 40 MHz (if a minimum of 10 Doppler cycles are required in the 50 μs laser pulse width). The Doppler frequency range may be adjusted by selection of the appropriate beam separation angle θ, as specified in Appendix 1. The large angles which are necessary for producing the higher Doppler frequencies, give improved axial spatial resolution and a greater number of fringes in the focal volume. When operating in the forward scatter mode, use of large values of θ results in a significant drop in the scatter signal level because of the strong angular dependence of the Mie scattering lobe pattern.

Forward scatter signal with good S/N were observed in about one out of ten laser pulses when using the natural scatterers found in laboratory air and an optical system similar to that shown in Fig. 14. Because of the low scatter signal rate and the increased bandwidth requirements involved with processing the pulsed laser signals (they are beyond the capabilities of the Sony AV 3650 tape recorder, f_{max} ~ 3.5 MHz), the forward scatter mode using the pulsed argon laser was considered unacceptable.

Back-scattering signals were only obtained using a seeded flow; no Doppler signals were observed for unseeded laboratory air using the optical arrangement of Fig. 13.

Forward Scattering Using a 1 mW He Ne Laser

Laser Doppler measurements can be made in the forward scatter fringe mode with a low power laser (≳ 1 mW), using the natural air contaminants present in a relatively clean environment. Typically we have found that out-of-doors conditions constitute an enhancement of the number of scatter events of ~ 100 over our laboratory conditions. This is due mainly to the greater abundance of the larger scattering particles.

The arrangement used for forward scattering with the He-Ne laser is shown in Fig. 14; the axial length of the probe volume (~ 2M) is too large for the present application but can be reduced at the expense of the scatter signal rate. An attractive feature of this particular system is the relatively low cost of the components.

Fig. 1a
UTIAS ACV test facility.

Fig. 1b
Control room and service bay.

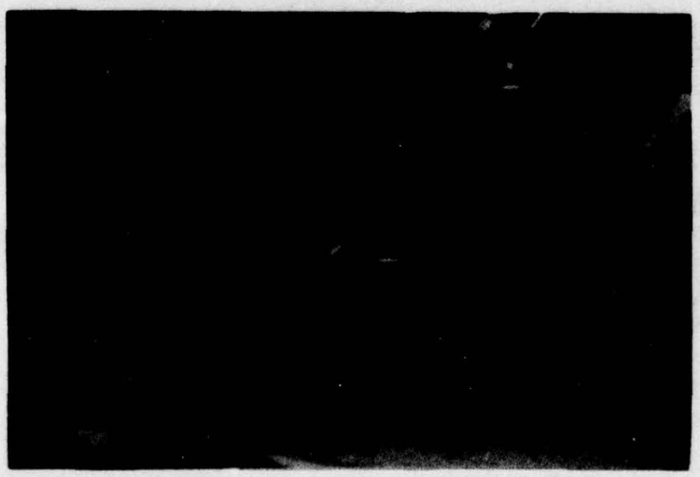


Fig. 1c
ACV just past LDV
Observation station.

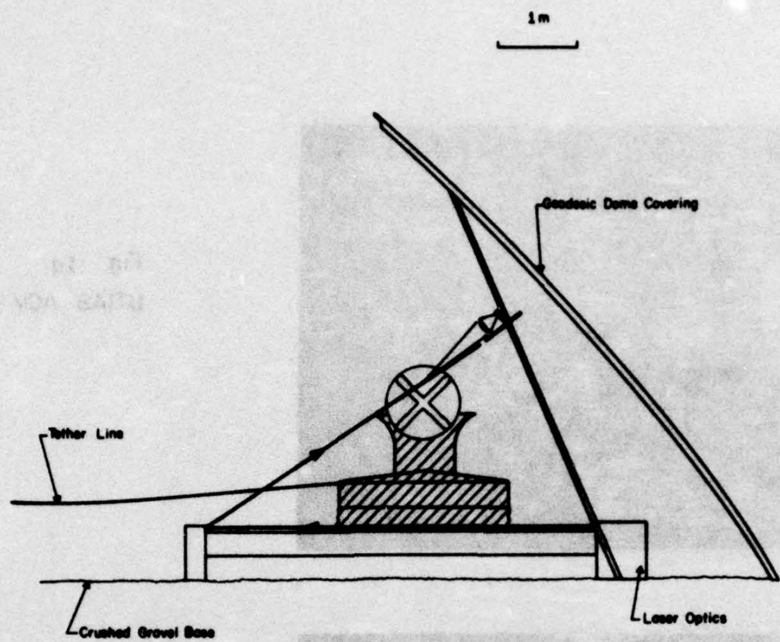


Fig. 2 ACV in hovering position on UTIAS testing track

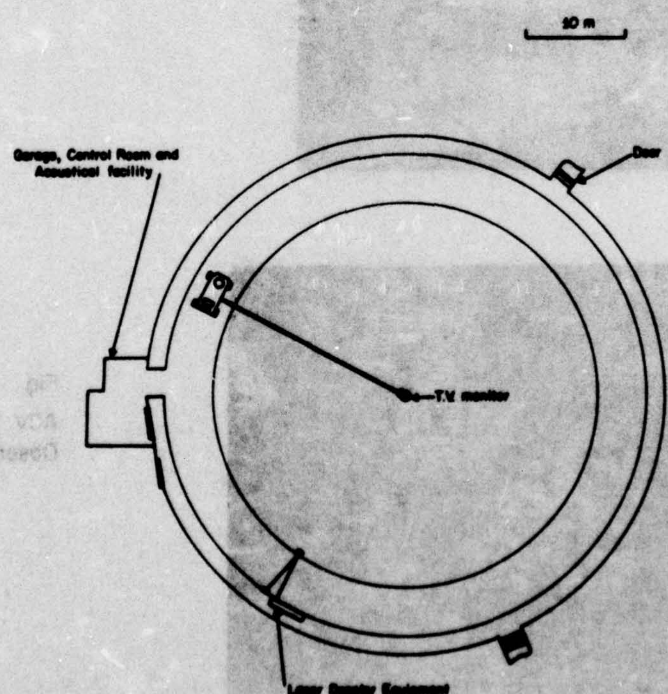


Fig. 3 Plan view of the ACV testing track

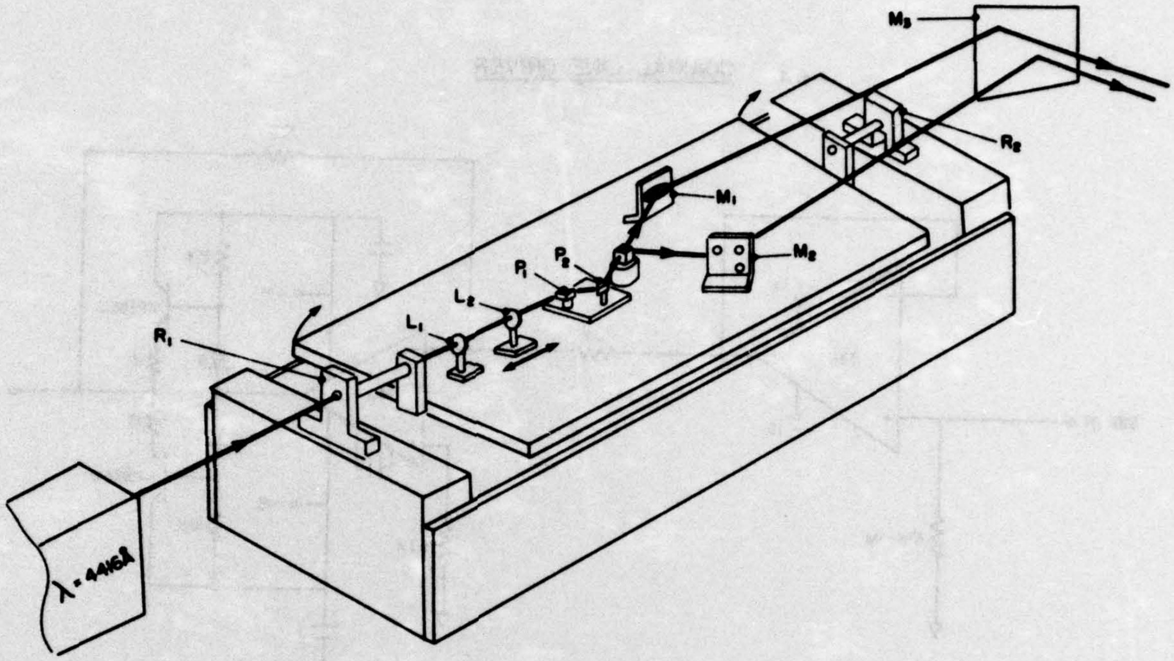


Fig. 4a LASER ANEMOMETER (HOVERCRAFT)

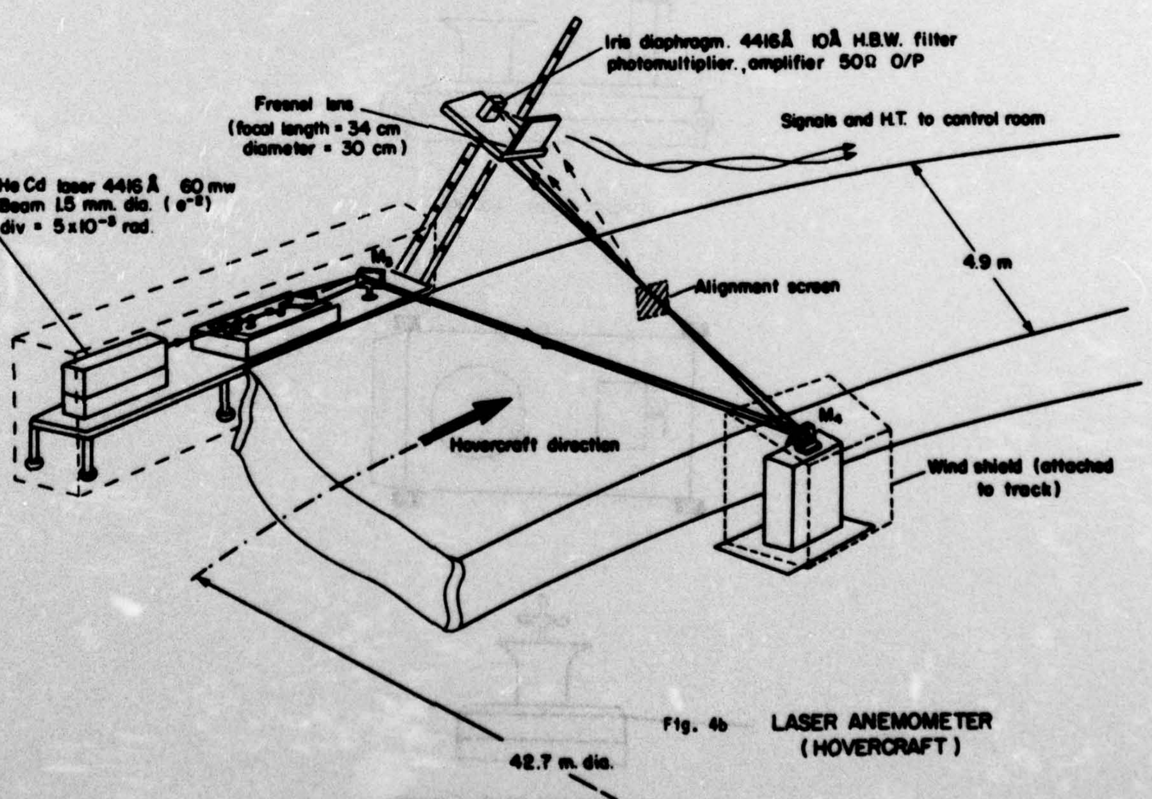
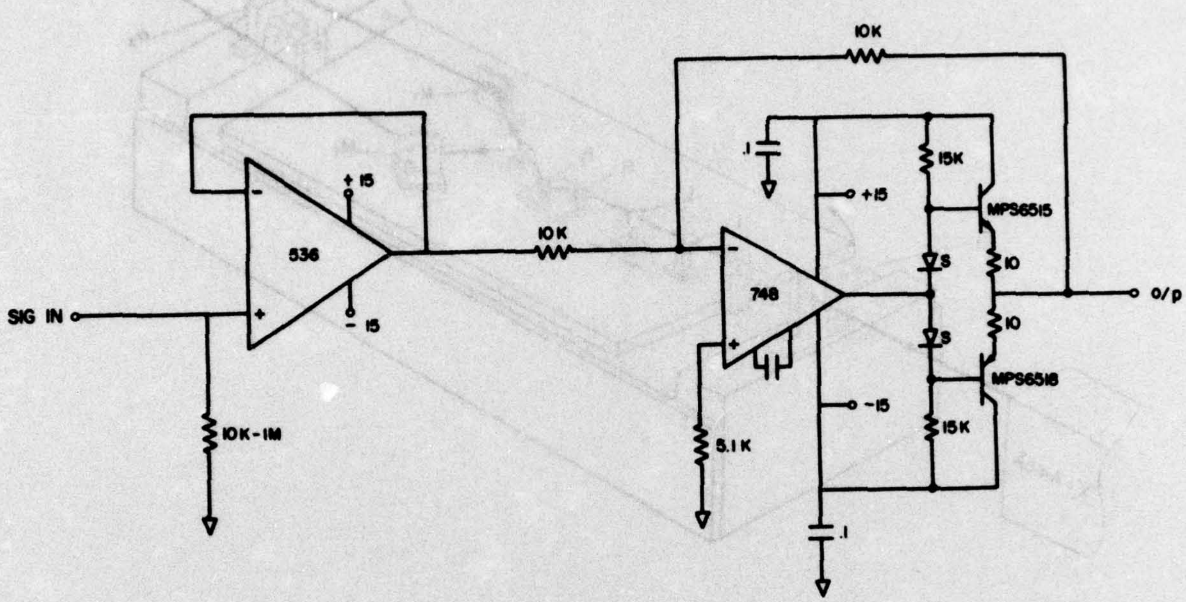


Fig. 4b LASER ANEMOMETER (HOVERCRAFT)

Fig. 5 COAXIAL LINE DRIVER



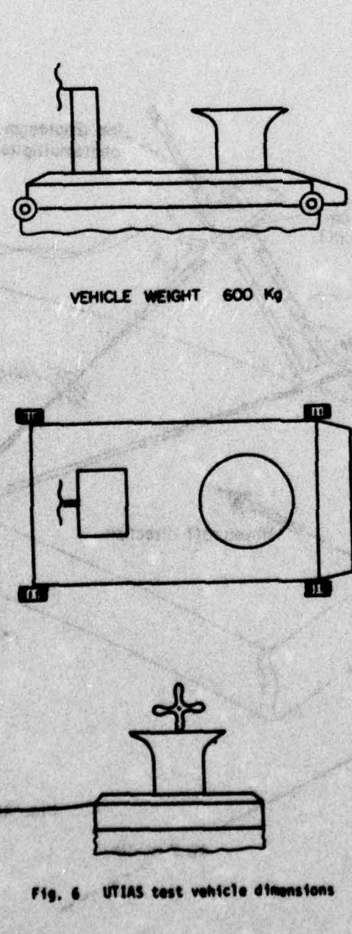
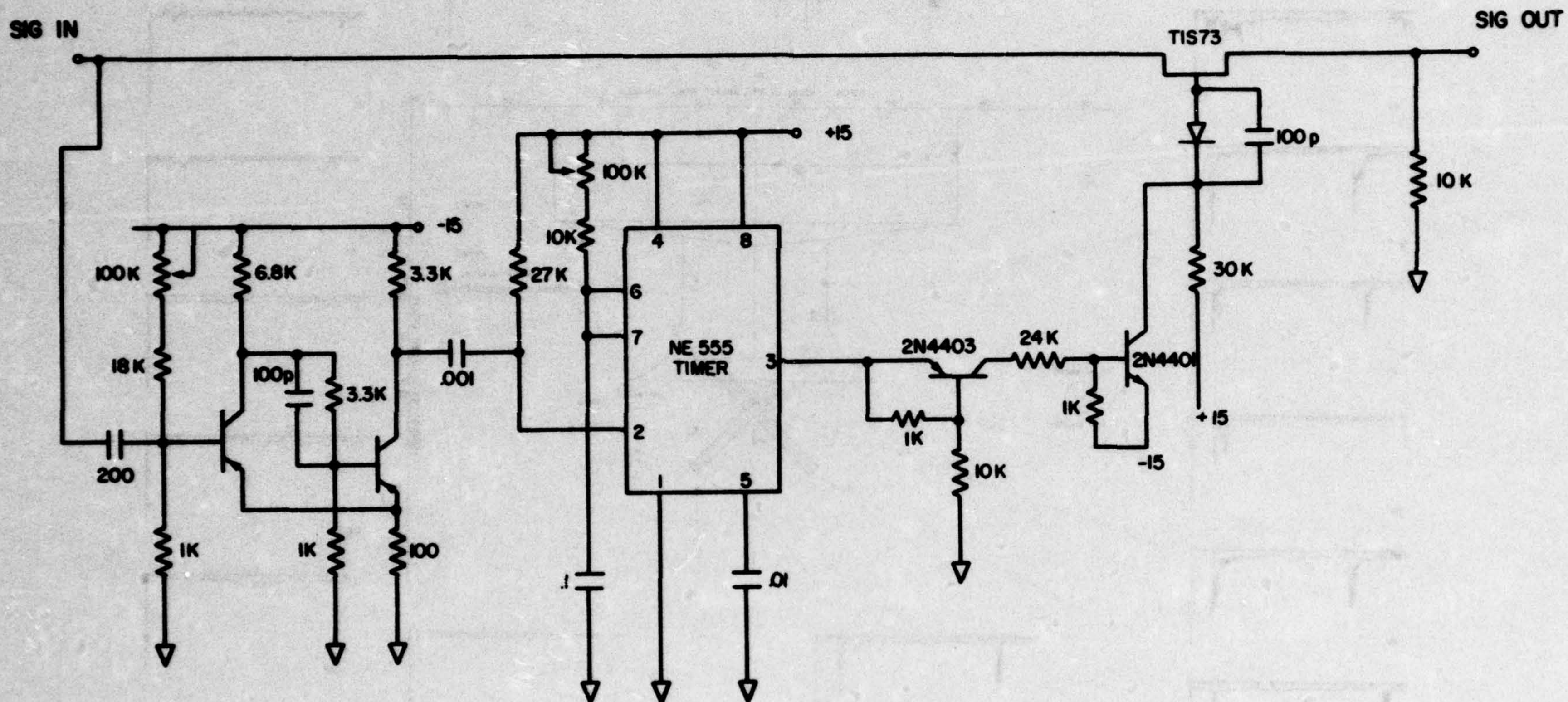


Fig. 6 UTIAS test vehicle dimensions

Fig. 7 **NOISE SUPPRESSION CIRCUIT**



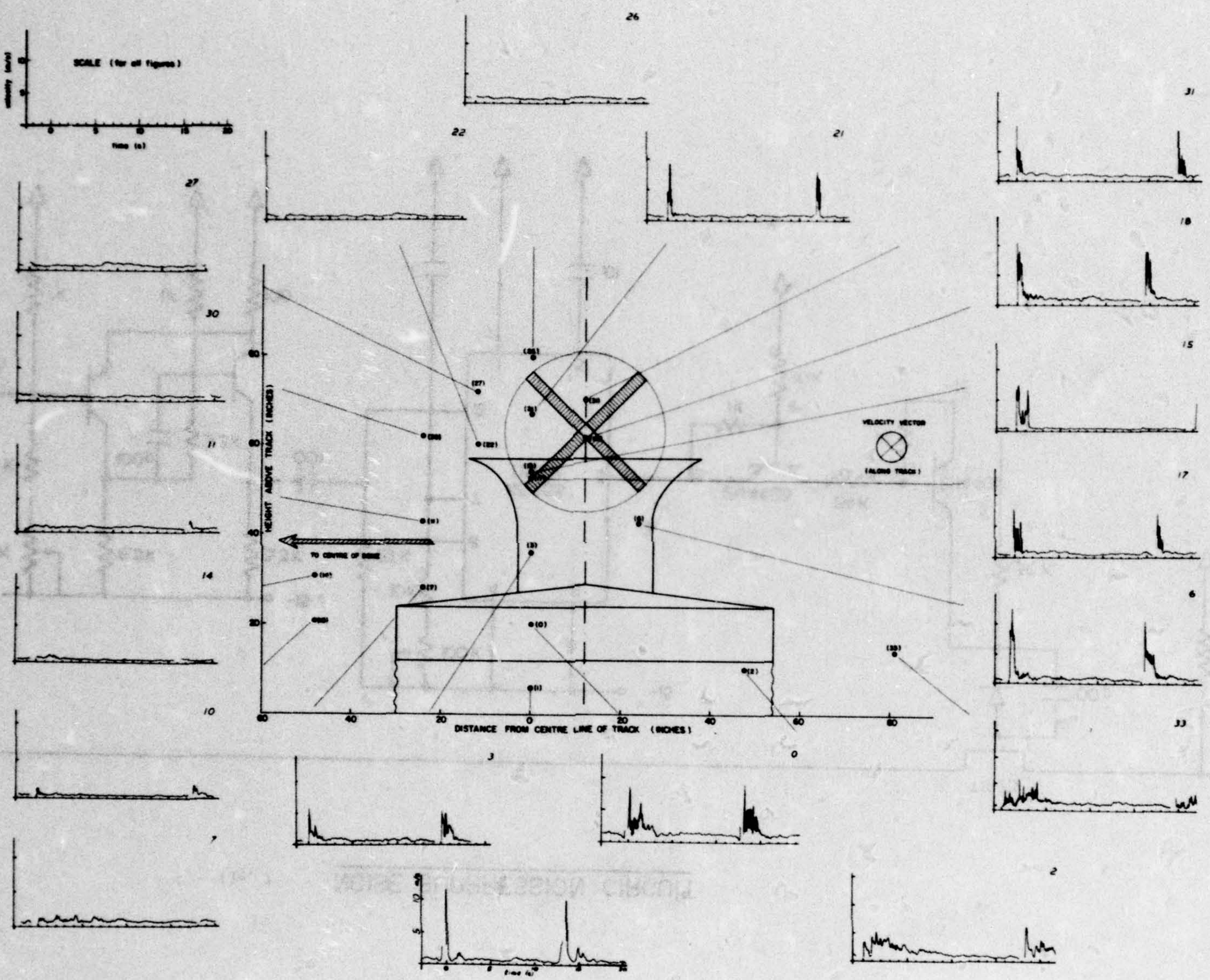


FIG. 8 AIR VELOCITY COMPONENTS ALONG TRACK DETERMINED FROM L.D.V.

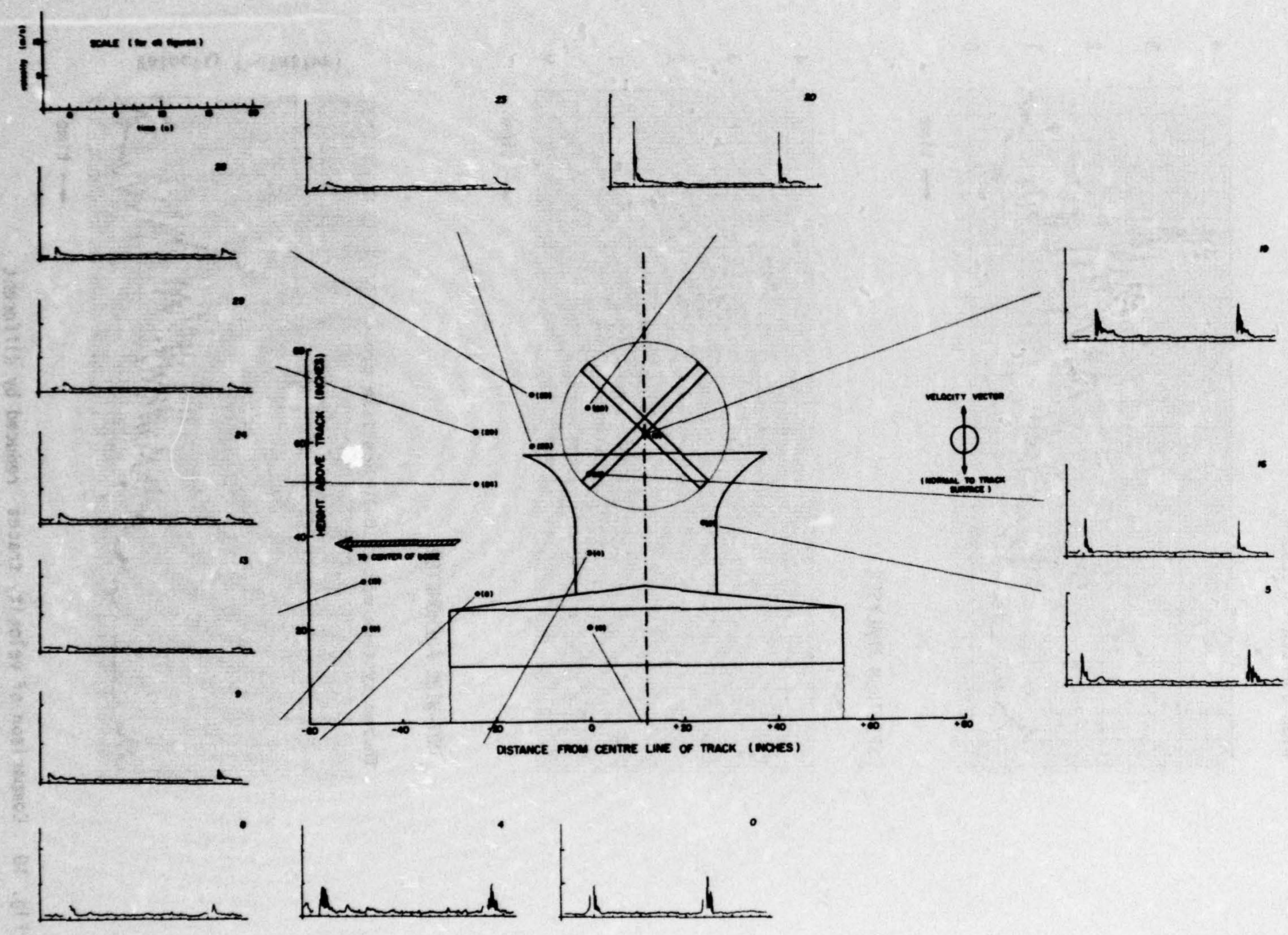


FIG. 9 AIR VELOCITY COMPONENTS PERPENDICULAR TO TRACK DETERMINED FROM L.D.V.

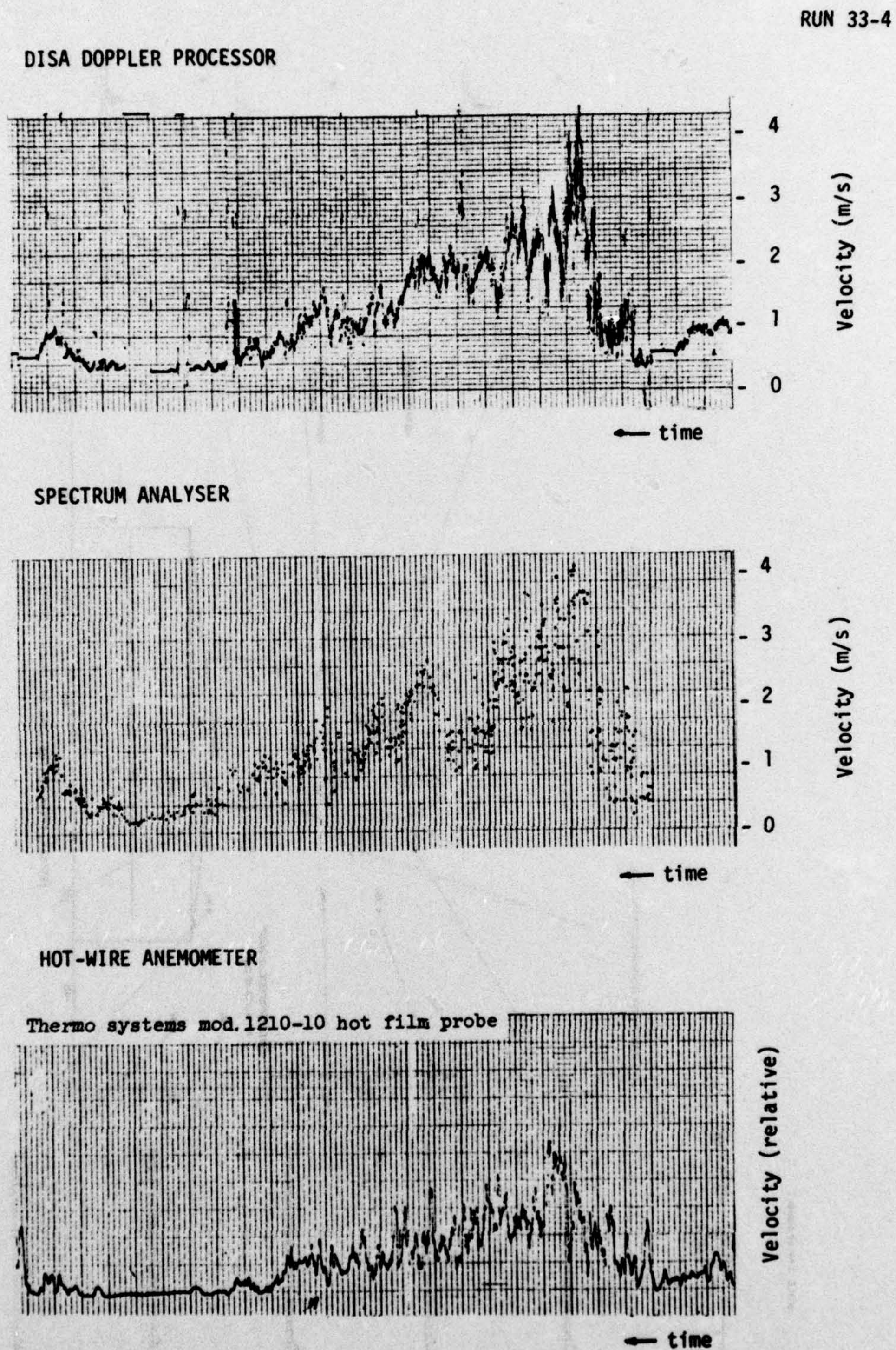


Fig. 10 Comparison of velocity traces reduced by different techniques

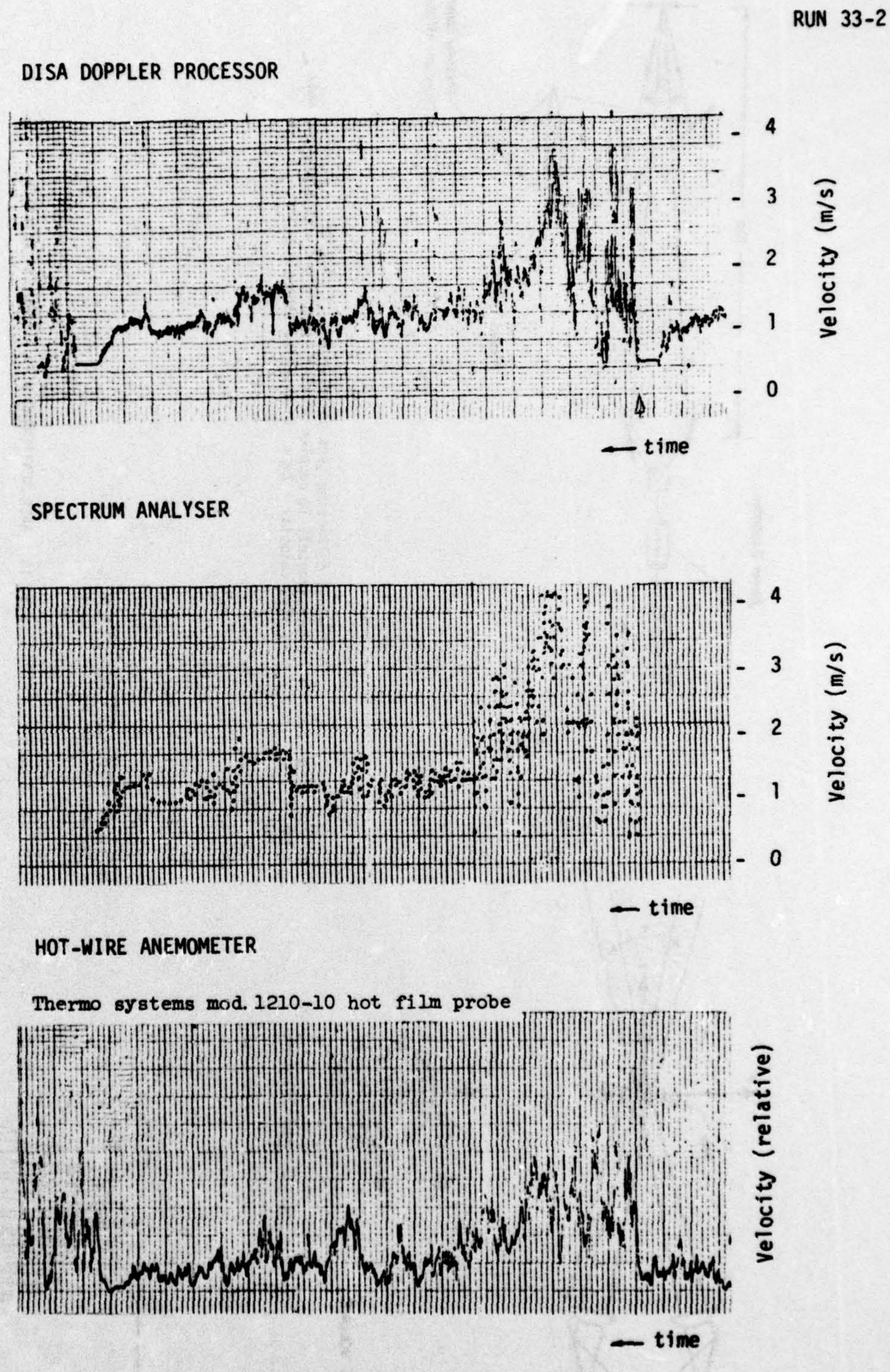


Fig. 11 Comparison of velocity traces reduced by different techniques

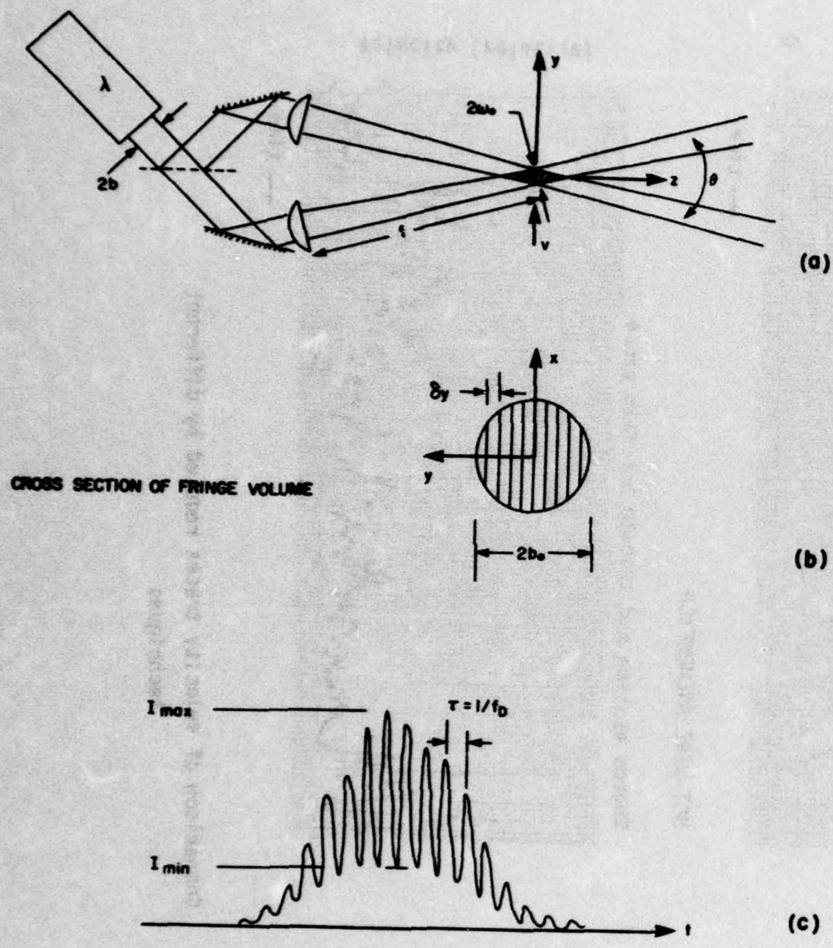
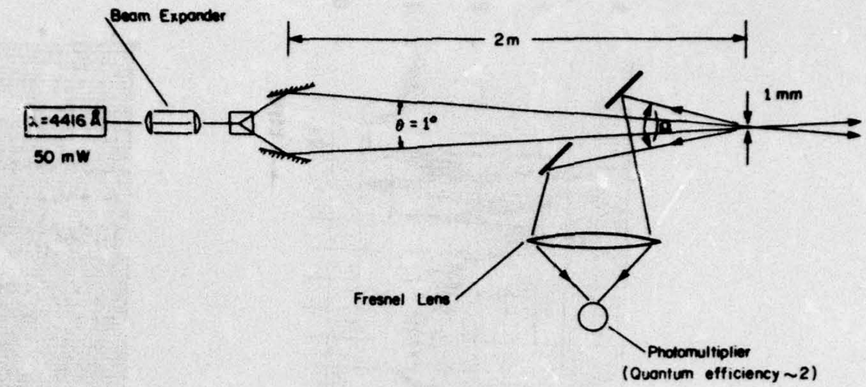
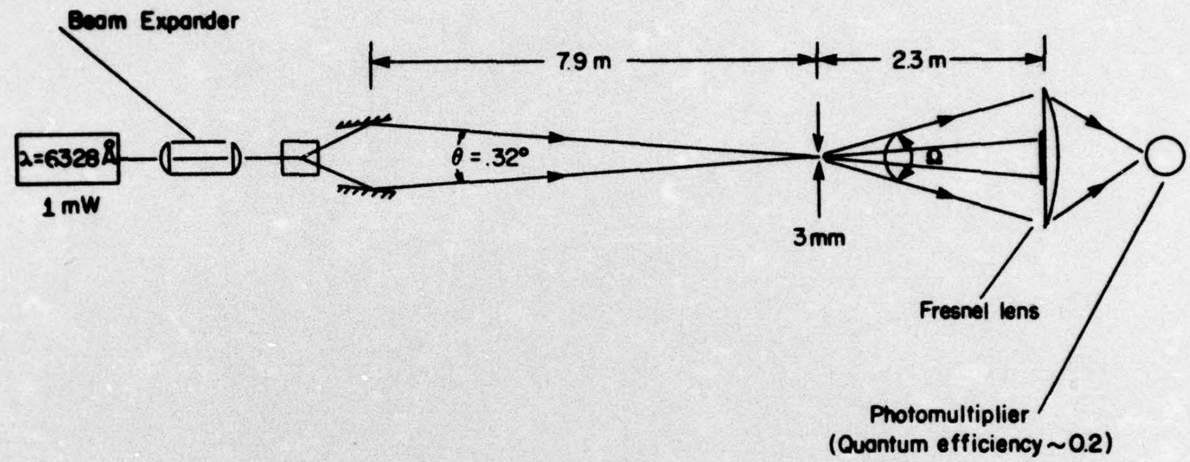


Fig. 12 SOME LASER DOPPLER FRINGE MODE PARAMETERS



Fresnel collecting lens solid angle Ω = .049 sr
Approximately 10 doppler scatter signals/sec with S/N ≥ 10 and
a flow velocity = 2m/s in unseeded laboratory air.

Fig. 13 BACK SCATTERING WITH A 50mW He Cd LASER



Fresnel collecting lens solid angle Ω = .014 Sr
Approximately 10 doppler scatter signals/sec with S/N ≥ 20 and
a flow velocity = 10m/s in unseeded laboratory air

Fig. 14 FORWARD SCATTERING WITH A 1mW He Ne Laser

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Davies, W. E. R. and deLeeuw, J. H.   15 pages   14 figures

1. Anemometry   2. Laser Doppler   3. Hovercraft Wake

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A video tape recorder was used to record all the laser Doppler data, which could then be processed by an oscilloscope, a spectrum analyser or a DISA 55L signal processor.

Results are presented which show that the stabilized wake effects are minimal for the UTIAS ACV and its associated facility.

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